Predictability in Unstable, Continuous Systems

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LONG-TERM GOALS

My long-term goal in this project is to improve our ability to predict environmental conditions using dynamical models.

OBJECTIVES

The central objective of my research in this project is to understand the mathematical and physical connections between the bred-growing-mode technique recently developed for numerical weather prediction, the Lyapunov vectors and exponents of dynamical systems theory, and the local instability theories of geophysical fluid dynamics. My intent is to gain insight into fundamental mathematical and physical aspects of predictability in unstable (irregular, chaotic) continuous systems.

APPROACH

I am using a combination of analytical and numerical methods to study a variety of simplified mathematical and physical models.

WORK COMPLETED

I have completed an initial study of Lyapunov and singular vectors in the framework of the periodic orbit analysis of a coupled system of ordinary and partial differential equations describing wave-mean interaction in a weakly nonlinear, baroclinically unstable, quasi-geostrophic flow. The leading unstable periodic orbits of the weakly nonlinear baroclinic system have been computed numerically in asymptotically periodic and chaotic regimes. In the case of periodic orbits, the Lyapunov vectors are computed using Floquet theory. Floquet and singular vectors have been computed and compared for the leading periodic orbit in asymptotically periodic and chaotic regimes. In addition, I have carried out some closely related computations as part of an incipient collaboration with Eli Tziperman (Weizmann Institute, Israel) on periodic orbits and predictability in the Cane-Zebiak coupled tropical ocean-atmosphere model.

This project has also provided partial support for several other efforts, including a set of lectures given at the 1999 CalTech Summer School on Lagrangian Transport, Stirring, and Mixing in Geophysical Flows, a collaboration with Roger Temam and Shouhong Wang (Indiana University) on the

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mathematical properties of the planetary geostrophic equations (Samelson et al. 1998, 1999, submitted; Samelson, 1999a), and observations and modeling of the lower atmosphere along the Oregon coast during summer 1999 that involved collaboration with and support of the remote sensing, aircraft, and modeling activities of Melanie Wetzel (DRI, Reno), Gabor Vali (U. Wyoming), and William Thompson (NRL Monterey) associated with the COSAT experiment.

RESULTS

The Floquet vectors of the leading periodic orbits tend to fall into two classes, the first dominated by baroclinic wave dynamics and the second associated with the decay of higher meridional modes of the zonall mean flow. The leading singular vector tends to contain contributions primarily from the first class of Floquet vectors, indicating that the presence of decaying zonal modes does not generally lead to artificial singular vectors associated with rapidly decaying modes that are unlikely to have substantial initial excitations. The analysis of leading periodic orbits and their Floquet eigenvectors gives a useful and efficient description of the dynamical evolution when the attractor geometry is sufficiently simple. The analysis also shows that in general it is necessary to know the amplitude of the disturbance to (or error in) the initial state, and the geometry of the attractor, to conclude whether it is appropriate to compute singular vectors in the subspace of the unstable Lyapunov vectors, an approach that has been advocated by other investigators.

IMPACT/APPLICATIONS

Results from this theoretical and numerical modeling effort will contribute to the overall goal of improving atmospheric and oceanic prediction models through ensemble prediction techniques.

TRANSITIONS

RELATED PROJECTS

This work is part of the ONR Predictability DRI. The coastal meteorological research (Samelson, 1999b; Burk et al., 1999) has been supported primarily by the NOPP project "Prediction of Wind-Driven Circulation" (PI's J. S. Allen and J. Barth) and by the ONR project "Dynamics of Forced Coastal-Trapped Disturbances" (PI A. Rogerson).

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PUBLICATIONS

Samelson, R., R. Temam, and S. Wang, Smooth solutions and attractor dimension bounds for planetary geostrophic ocean models. Q. J. Roy. Met. Soc., submitted.